Measurements of Leptonic $B$ Decays from $BaBar$

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for the $BaBar$ collaboration

ICHEP 2004
Heavy Quark Mesons and Baryons session
Overview

• Motivations for studying leptonic $B$ decays
  – SM and beyond-SM considerations
    
    \[ B^+ \rightarrow l^+ \nu_l \]
    \[ B^0 \rightarrow l^+ l^- , l^+ l^- , \quad B^0 \rightarrow \nu \nu , \nu \nu \gamma \]
    \[ B^+ \rightarrow K^+ \nu \nu \]

• Analyses
  – Decays to $\nu X$ states: tag-recoil analyses
    • general methods
    • specific results
  – $B^0 \rightarrow l^+ l^-$ analysis

• Conclusions and prospects

All results are preliminary unless otherwise noted
Leptonic $B$ decays to $\tau^+ \nu$, $l^+ l^-$, $\nu \overline{\nu}$

- Leptonic decays of heavy-quark mesons provide a laboratory
  - For testing straightforward SM predictions:
    \[ \mathcal{B}(B^+ \rightarrow l^+ \nu) = \frac{G_F^2 |V_{ub}|^2}{8\pi} f_B^2 \tau_B m_B m_l^2 \left[ 1 - \frac{m_l^2}{m_B^2} \right]^2 \]

In SM: $B(B^+ \rightarrow \tau^+ \nu_{\tau}) \sim (9.3\pm3.9) \times 10^{-5}$ (PDG’04 $V_{ub}, f_B$)
(pred.) $B(B^+ \rightarrow \mu^+ \nu_{\mu}) \sim (4.2\pm1.8) \times 10^{-7}$

- For searching for non-SM effects in highly suppressed processes. Some new-physics in loops (e.g., SUSY) can enhance these by orders of magnitude. Also LFV?

In SM: $B(B^0 \rightarrow \mu^+\mu^-) \sim 8 \times 10^{-11}$
(pred.) $B(B^0 \rightarrow \nu \overline{\nu}) \sim$ zero

Note helicity suppression
Calculable in Lattice QCD
$B$ decays to $K/\pi^+ \nu \bar{\nu}$

- Motivation
  - The flavor-changing neutral current decays $B \rightarrow K/\pi^+ \nu \bar{\nu}$ occur in the Standard Model via one-loop radiative penguin and box diagrams:
  - SM expectation: $B(B^+ \rightarrow K^+ \nu \bar{\nu}) \sim (3.8^{+1.2}_{-0.6}) \times 10^{-6}$, $B(B^+ \rightarrow \pi^+ \nu \bar{\nu}) \sim 2.8 \times 10^{-7}$
  - Their analysis is theoretically very clean; observation of these processes would be complementary to the observation of $B \rightarrow K(\ast) l^+ l^-$ and will help in understanding the basic Standard Model physics of such diagrams.
  - These also present another opportunity for the observation of new-physics effects in the loops.
Tag-recoil analyses: $B_1 \rightarrow tag, B_2 \rightarrow \tau^+\nu, K^+\nu\bar{\nu}, \nu\bar{\nu}$

Neutrino analyses require extra kinematic and/or particle selection constraints.
Use $BB$ initial state to achieve this.

- Explicitly identify the decay of one “tag” $B$
  - Fully reconstructed $B \rightarrow D + X$ hadronic decays . . . full knowledge of kinematics
  - $b \rightarrow c$ semileptonic decays . . . . . . . . . . . . . . . . . . some ambiguity, more tags

- Study the recoil for the decay of interest
  - Typically we require the recoil to have
    - Exact charged-particle content expected for signal
    - Number and total energy $E_{extra}$ of neutrals observed less than an analysis-dependent threshold
  - Tagging efficiencies can be checked by “double-tagging”

All analyses apply anti-continuum shape cuts
Semileptonic \((b \rightarrow c + l^- + X)\) tags

- Selection varies somewhat with analysis
  - The lepton must be either an electron or muon with positive PID and \(p^* > \sim 1\text{GeV/c}\)
  - Kaons are identified by the DIRC
  - \(D\) mesons are reconstructed in several \(K + N\pi\) final states, identified by inv. mass \(\pm 3\sigma\)
  - \(D^*\) mesons are identified by the mass difference \(\Delta m = m_{D^*} - m_D\)
  - The semileptonic decay kinematics are enforced by looking at the variable \(\cos \theta_{B,D(*)l}\), defined as and requiring it to be in the physical region. Some of the analyses are more tolerant of missing/extra particles (higher \(D^*(*)\) states), trading purity for statistics.

<table>
<thead>
<tr>
<th>Analysis</th>
<th>(\tau^+\nu_\tau) (I)</th>
<th>(\tau^+\nu_\tau) (II)</th>
<th>(K^+ \nu \bar{\nu})</th>
<th>(\nu\bar{\nu}, \nu\bar{\nu} \gamma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(D) selection</td>
<td>(D^0 \rightarrow K\pi, K3\pi, K\pi\pi^0, K_S^0\pi\pi)</td>
<td>(D^0 \rightarrow K\pi, K3\pi, K\pi\pi^0, K_S^0\pi\pi)</td>
<td>(D^0 \rightarrow K\pi, K3\pi, K\pi\pi^0)</td>
<td>(D^+ \rightarrow K\pi\pi) (D^0 \rightarrow K\pi, K3\pi, K\pi\pi^0)</td>
</tr>
<tr>
<td>Tag selection</td>
<td>(D^0 l^- \overline{\nu}_l X) (X: \gamma, \pi^0, \text{nothing})</td>
<td>(D^{*0} l^- \overline{\nu}_l) (D^{*0} \rightarrow D^0 \pi^0, D^0 \gamma)</td>
<td>(D^0 l^- \overline{\nu}_l X) (X) unseen</td>
<td>(D^{<em>+} l^- \overline{\nu}_l X, D^{+} l^- \overline{\nu}_l X) (D^{</em>+} \rightarrow D^0 \pi^+)</td>
</tr>
<tr>
<td>(\cos \theta_{B,D(*)l}) requirement</td>
<td>(-2.5 &lt; \cos \theta &lt; 1.1)</td>
<td>(-1.1 &lt; \cos \theta &lt; 1.1)</td>
<td>(-2.5 &lt; \cos \theta &lt; 1.1)</td>
<td>(-2.5 &lt; \cos \theta &lt; 1.1)</td>
</tr>
</tbody>
</table>
Hadronic ($B \to D + X$) tags

- An additional $B^- \to D^{(*)0} + X^-$ hadronic tag sample is used for the $K/\pi^+\pi^-\pi^0$ and $\tau^+\nu_\tau$ (I) analyses:
  - $D$ mesons are reconstructed in $D^0 \to K^-\pi^+, K^-\pi^+\pi^-, K^-\pi^+\pi^0, K_S^0\pi^+\pi^-$
  - In the $\tau^+\nu_\tau$ (I) analysis, $D^{*0} \to D\pi^0$ candidates are formed as well. The $X^-$ system is composed of 1-5 $\pi^\pm$, 0-2 $K^\pm$, 0-2 $\pi^0$, and 0-1 $K_S^0$.
  - In the $K^+\pi^-\pi^0$ analysis, only $D^0$ are considered, and the $X^-$ system is composed of 1-5 mesons, including $\pi^\pm$, $K^\pm$, and $\pi^0$, with no more than two $\pi^0$ used.
  - $B$ mesons are identified with the kinematic variables $\Delta E=E_B-E_{\text{beam}}$ and the beam-energy substituted mass $m_{ES} = \sqrt{\left[(s/2 + \vec{p} \cdot \vec{p}_B)^2/E^2\right] - |\vec{p}_B|^2}$.
$B^+ \rightarrow \tau^+ \nu_\tau$ analysis I

- **Semileptonic tags:** ML fit to $E_{\text{extra}}$
  - Consider $\tau^+ \rightarrow e^+ \nu_e \bar{\nu}_\tau$ and $\mu^+ \nu_\mu \bar{\nu}_\tau$
  - Signal: $14.8 \pm 6.3$ events
  - Background: $115.2 \pm 11.8$ events
  - Significance as a signal: $2.3 \sigma$ (stat. only)
  - Limit (CLs method, incl. syst.): $B(B^+ \rightarrow \tau^+ \nu_\tau) < 6.7 \times 10^{-4}$ (90%CL)

- **Hadronic tags:** event counts
  - $\tau^+ \rightarrow \pi^+ \bar{\nu}_\tau$, $\pi^+ \pi^0 \bar{\nu}_\tau$, $\pi^+ \pi^- \pi^+ \bar{\nu}_\tau$, $e^+ \nu_e \bar{\nu}_\tau$, $\mu^+ \nu_\mu \bar{\nu}_\tau$
  - Signal in kin./$E_{\text{extra}}$ regions: 15 events
  - Background: $17.2 \pm 2.1$ (stat) $\pm 1.3$ (syst) events
  - Limit (L-ratio w/ null hypothesis): $B(B^+ \rightarrow \tau^+ \nu_\tau) < 4.2 \times 10^{-4}$ (90%CL)

- **Combined limit:** $B(B^+ \rightarrow \tau^+ \nu_\tau) < 4.2 \times 10^{-4}$ (90%CL)

$\tau$ branching fraction
given tag
backgr'nd estimate

<table>
<thead>
<tr>
<th>selection</th>
<th>$B$ (%)</th>
<th>$\varepsilon_i$ (%)</th>
<th>$b_i$</th>
<th>$\sigma_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e\nu\nu$</td>
<td>17.84 $\pm$ 0.06</td>
<td>3.4 $\pm$ 0.1</td>
<td>0.7 $\pm$ 0.4 $\pm$ 0.1</td>
<td>2</td>
</tr>
<tr>
<td>$\mu\nu\nu$</td>
<td>17.37 $\pm$ 0.06</td>
<td>1.9 $\pm$ 0.1</td>
<td>0.9 $\pm$ 0.5 $\pm$ 0.1</td>
<td>0</td>
</tr>
<tr>
<td>$\pi\nu$</td>
<td>11.06 $\pm$ 0.11</td>
<td>2.6 $\pm$ 0.1</td>
<td>1.3 $\pm$ 0.6 $\pm$ 0.2</td>
<td>2</td>
</tr>
<tr>
<td>$\pi^-\pi^+\pi^-\nu$</td>
<td>9.52 $\pm$ 0.10</td>
<td>0.6 $\pm$ 0.1</td>
<td>4.3 $\pm$ 1.0 $\pm$ 0.3</td>
<td>4</td>
</tr>
<tr>
<td>$\pi^-\pi^0\nu$</td>
<td>25.41 $\pm$ 0.14</td>
<td>2.0 $\pm$ 0.1</td>
<td>10.0 $\pm$ 1.6 $\pm$ 1.3</td>
<td>7</td>
</tr>
<tr>
<td>all</td>
<td>81.20 $\pm$ 0.22</td>
<td>10.5 $\pm$ 0.2</td>
<td>17.2 $\pm$ 2.1 $\pm$ 1.3</td>
<td>15</td>
</tr>
</tbody>
</table>

$B\bar{B}$ pairs used: $(88.9 \pm 1.0) \times 10^6$
$B^+ \rightarrow \tau^+ \nu_\tau$ analysis II – $D^* l \bar{\nu}$ tags

- Refinement of semileptonic part of analysis I
  - Tighten tag selection to require clean $D^*$
- Consider $\pi^+ \nu_\tau$, $\pi^+ \pi^0 \nu_\tau$, $\pi^+ \pi^- \pi^+ \nu_\tau$, $e^+ \nu_\tau$, and $\mu^+ \nu_\mu \nu_\tau$
  - Mode-dependent kinematic selections
- Determine signals by counting events in $E_{\text{extra}}$ regions

<table>
<thead>
<tr>
<th>Mode</th>
<th>$e^+ \nu_\tau$</th>
<th>$\mu^+ \nu_\mu \nu_\tau$</th>
<th>$\pi^+ \nu_\tau$</th>
<th>$\pi^+ \pi^0 \nu_\tau$</th>
<th>$\pi^+ \pi^- \pi^+ \nu_\tau$</th>
</tr>
</thead>
<tbody>
<tr>
<td>BG incl.</td>
<td>15.2±3.1</td>
<td>8.1±2.1</td>
<td>55.3±7.4</td>
<td>29.8±5.1</td>
<td>25.1±3.4</td>
</tr>
<tr>
<td>systematic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observed</td>
<td>13</td>
<td>10</td>
<td>72</td>
<td>30</td>
<td>26</td>
</tr>
</tbody>
</table>

(Signal MC scaled to $BF=10^{-3}$)

Validation:
- Signal efficiency, $E_{\text{extra}}$:
  - Double tags
- Backgrounds:
  - Control samples with extra tracks

Result:
$B(B^+ \rightarrow \tau^+ \nu_\tau) < 4.3 \times 10^{-4}$ (90% CL)

Combined with hadronic tags:
(independent, 88.9M $BB$)
$B(B^+ \rightarrow \tau^+ \nu_\tau) < 3.3 \times 10^{-4}$ (90% CL)

Also recall (PRL 92, 221803, ’04)
$BaBar\ B(B^+ \rightarrow \mu^+ \nu_\mu) < 6.6 \times 10^{-6}$

Gregory Dubois-Felsmann – 5 August 2004
**$B^+ \rightarrow K/\pi^+ \nu \bar{\nu}$ analysis**

- Uses tags of both types
  - Signal obtained from $E_{extra}/p_K$ region

<table>
<thead>
<tr>
<th>Tags</th>
<th>Hadronic</th>
<th>Semileptonic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background events (incl. systematics)</td>
<td>3.9±1.1</td>
<td>3.4±1.2 (non-peaking)</td>
</tr>
<tr>
<td>Signal events</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Efficiency (%)</td>
<td>0.055±0.005</td>
<td>0.115±0.009</td>
</tr>
<tr>
<td>Limit (90%CL) on $B(B^+ \rightarrow K^+\nu\bar{\nu})$</td>
<td>$6.2\times10^{-5}$</td>
<td>$7.0\times10^{-5}$</td>
</tr>
</tbody>
</table>

- Combined limit:
  $$B(B^+ \rightarrow K^+\nu\bar{\nu}) < 5.2\times10^{-5} \text{ (90\%CL)}$$

- Also possible to set limit on $B^+ \rightarrow \pi^+\nu\bar{\nu}$
  - Change PID requirement; use only hadronic analysis:
    $$B(B^+ \rightarrow \pi^+\nu\bar{\nu}) < 1.0 \times 10^{-4} \text{ (90\%CL)}$$

**BaBar preliminary**

Leptonic B Decays - BaBar preliminary

Gregory Dubois-Felsmann – 5 August 2004
\( B^0 \rightarrow \text{invisible (ν \bar{ν}), ν \bar{ν} γ analysis} \)

- Semileptonic tags only: \( B^0 \rightarrow D^{(*)+} l^- \bar{ν} \) \( (D^{*+} \rightarrow D^0 \pi^+) \)
- Require “nothing” in recoil: no charged tracks, limited neutrals
- Signal obtained from ML fit to \( E_{\text{extra}} \) (KEYS shapes from MC):
  - \( ν \bar{ν} \):
    - Signal: \( 17 \pm 9 \), background \( 19^{+10}_{-8} \) events
  - \( ν \bar{ν} γ \):
    - Signal: \( -1.1^{+2.4}_{-1.9} \), background \( 28^{+6}_{-5} \)

- Upper limits:
  - Systematics for \( ν \bar{ν} (ν \bar{ν} γ) \):
    - Additive: \( 7.4 (4.3) \) events
    - Multiplicative: \( 10.9\% (11.1\%) \)
  - Frequentist limit-setting procedure
    - Systematics taken as Gaussian
  - \( B(B^0 \rightarrow \text{invisible}) < 22 \times 10^{-5} \) (90\%CL)
  - \( B(B^0 \rightarrow ν \bar{ν} γ) < 4.7 \times 10^{-5} \) (90\%CL)*

* Depends on constituent quark model for Dalitz plot shape (Lu & Zhang, Phys. Lett. B 381, 349 (1996))

\[ B \bar{B} \text{ pairs used: } (88.5±1.0) \times 10^6 \]
$B^0 \rightarrow l^+ l^- (e^+e^-, \mu^+\mu^-, e^+\mu^-)$ analysis overview

- Very straightforward $m_{ES}, \Delta E$ reconstruction
  - Extremely clean monochromatic kinematics
  - Key features:
    Lepton identification, rejection of QED and $qq$ backgrounds
  - Bremsstrahlung recovery applied to $e$’s
  - Strategy: define cuts for ID and purity, and sideband region, blind signal box in $m_{ES}, \Delta E$

- Selection variables
  - $| \cos \theta_T |$: $\theta_T$ is angle between thrust axes of $l^+l^-$ candidate and rest of event
  - $m_{ROE}$: invariant mass of rest of event
  - $R_2$: norm’d 2$^{\text{nd}}$ Fox-Wolfram moment
  - $N_{\text{trk}} + \frac{1}{2}N_{\gamma}$: measure of multiplicity
  - $E_{\text{EMC}} < 11$ GeV, rejects QED

Signal MC (blue) vs. sideband data
$B^0 \rightarrow l^+ l^- (e^+e^-, \mu^+\mu^-, e^+\mu^-)$ results

- Unblinded data for $(122.5 \pm 1.2) \times 10^6 B\bar{B}$:

<table>
<thead>
<tr>
<th>Signal regions</th>
<th>Events observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^+e^-$</td>
<td></td>
</tr>
<tr>
<td>$\mu^+\mu^-$</td>
<td></td>
</tr>
<tr>
<td>$e^\pm\mu^\mp$</td>
<td></td>
</tr>
</tbody>
</table>

### Events observed

<table>
<thead>
<tr>
<th>channel</th>
<th>$N_{\text{obs}}$</th>
<th>$N_{\text{exp}}^{\text{bg}}$</th>
<th>$\varepsilon$ [%]</th>
<th>$B_{UL}(B^0 \rightarrow \ell^+\ell^-)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^0 \rightarrow e^+e^-$</td>
<td>0</td>
<td>0.71 ± 0.31</td>
<td>21.8 ± 1.2</td>
<td>$6.1 \times 10^{-8}$</td>
</tr>
<tr>
<td>$B^0 \rightarrow \mu^+\mu^-$</td>
<td>0</td>
<td>0.72 ± 0.26</td>
<td>15.9 ± 1.1</td>
<td>$8.3 \times 10^{-8}$</td>
</tr>
<tr>
<td>$B^0 \rightarrow e^\pm\mu^\mp$</td>
<td>2</td>
<td>1.29 ± 0.44</td>
<td>18.1 ± 1.2</td>
<td>$18 \times 10^{-8}$</td>
</tr>
</tbody>
</table>

- Systematics:
  - Dominated by multiplicative uncertainties on the efficiency, primarily from tracking and $\mu$ ID:
    - 5.7%, 7.1%, 6.8% for $e^+e^-$, $\mu^+\mu^-$, $e^+\mu^-$

- Limits:
  - Using the Barlow method:
    - $B(B^0 \rightarrow e^+e^-) < 6.1 \times 10^{-8}$ (90%CL)
    - $B(B^0 \rightarrow \mu^+\mu^-) < 8.3 \times 10^{-8}$ (90%CL)
    - $B(B^0 \rightarrow e^+\mu^-) < 18 \times 10^{-8}$ (90%CL)

A substantial improvement on previous measurements!
Finding additional details

- $B^+ \rightarrow \mu^+\nu_\mu$
  - Published in PRL 92, 221803 (2004); hep-ex/0401002

- $B^+ \rightarrow \tau^+\nu_\tau$ (88.9M $BB$)
  - Submitted to PRL: hep-ex/0407038, BABAR-PUB-04/021

- $B^+ \rightarrow \tau^+\nu_\tau$ (124.1M $BB$, new semileptonic analysis with $D^{*0}l\bar{\nu}$ tags)
  - ICHEP04 conference paper, abstract #11-0933, BABAR-CONF-04/026

- $B^+ \rightarrow K^+\nu\bar{\nu}$
  - ICHEP04 conference paper, abstract #11-0937, BABAR-CONF-04/050, hep-ex/0408086

- $B^0 \rightarrow \nu\bar{\nu}, \nu\bar{\nu}\gamma$
  - Accepted for publication in PRL: hep-ex/0405071, BABAR-PUB-04/014; ICHEP abs. #11-0977

- $B^0 \rightarrow l^+l^-$
  - About to be submitted to PRL; BABAR-PUB-04/032; ICHEP abstract #11-0956
  - See also $D^0 \rightarrow l^+l^-$: hep-ex/0408023, BABAR-PUB-04/027, submitted to PRL; ICHEP #11-0964
Summary

- We have set upper limits on branching fractions of several rare leptonic and/or FCNC decays of $B$ mesons useful as …
  - checks of basic predictions for weak decays of heavy-quark mesons (e.g., $f_B$), and
  - probes for new physics beyond the Standard Model

- These decays have not yet come into sight

but some are now within an order of magnitude or less of the SM expectations…

- We have 2-3 times the data available already (>240M BB) and being analyzed, with another factor of two to come in the next few years…

- Some of these will very likely be observed one or two ICHEPs from now…
Additional slides
The \textit{BaBar} detector and dataset

Asymmetric C.M. for $Y(4S) \rightarrow B\bar{B}$, \( \beta\gamma \sim 0.56 \)

Work presented today

$B^+ \rightarrow \tau^+ \nu_\tau$

$(D^*l\nu \text{ tags})$

$B^0 \rightarrow l^+ l^-$

$B^+ \rightarrow \tau^+ \nu_\tau, \mu^+ \nu_\mu$

$B^+ \rightarrow K^+ \nu \nu$

$B^0 \rightarrow \nu \nu, \nu \nu \gamma$

Leptonic B Decays - BaBar preliminary
$B^+ \rightarrow \tau^+ \nu_\tau$ analysis I details

- For semileptonic tags $D^0 l^+ \nu_l X$, $\tau^+ \nu_\tau$ decays $e^+ \nu_e \nu_\tau$ and $\mu^+ \nu_\mu \nu_\tau$ are considered
  - Exactly one charged track originating near the interaction point,
  - Positively identified as an electron or muon, with $p^* < 1.2$ GeV/c.
  - Continuum quark and $\tau^+ \tau^-$ events are rejected by means of event shape cuts and a minimum invariant-mass requirement on triplets of charged tracks.
  - Require $-2.5 < \cos \theta_{B,Dl} < 1.1$; admits excited $D$ states with some unobserved particles
  - Signal determined from fit to shape of distribution of remaining neutral energy ($E_{\text{extra}}$)
    - Peaks near zero and at low values ($\sim 0.15$ GeV) for signal, from $X=($nil$)$ and $X=\gamma, \pi^0$, respectively; rising at larger $E_{\text{extra}}$ for principal backgrounds.

- For hadronic tags, we consider $\pi^+ \nu_\tau$, $\pi^+ \pi^0 \nu_\tau$, $\pi^+ \pi^- \pi^+ \nu_\tau$, $e^+ \nu_e \nu_\tau$, and $\mu^+ \nu_\mu \nu_\tau$
  - Total charge 0. Positive PID is required for charged tracks.
  - Extra $\pi^0$ or $K_S^0$ or high energy photons are rejected.
  - Characteristic kinematical and dynamical features of the $\tau$ decay modes are required
  - Minimum missing momentum (calculable using the fully reconstructed tag) req’d per mode
  - Signal determined by counting events in the signal region for each $\tau$ decay mode
    - $m_{ES} > 5.27$ GeV/c$^2$, $-0.09 < \Delta E < 0.06$ GeV
    - Background extrapolated from sideband $5.21 < m_{ES} < 5.26$ GeV/c$^2$, checked against simulation

168k tags
$B^+ \rightarrow \tau^+ \nu_\tau$ analysis II – $D^{*0}_{l\bar{\nu}}$ tags – details

- Refinement of semileptonic analysis, tightening tag selection
  - Require a $D^{*0}$, in either of its decays ($D^0\pi^0, D^0\gamma$)
  - Tight kinematic cut rejects other $D_X$:
    - $-1.1 < \cos \theta_{B,D^*l} < 1.1$
  - Select best $D$, $D^*$
  - Tag efficiency: $(1.818 \pm 0.074) \times 10^{-3}$

- Consider $\pi^+\nu_\tau$, $\pi^+\pi^0\nu_\tau$, $\pi^+\pi^-\pi^+\nu_\tau$, $e^+\nu_e\nu_\tau$, and $\mu^+\nu_\mu\nu_\tau$
  - Require 1 or 3 charged tracks of good quality & matching PID
  & a good $\pi^0$ ($E\gamma > 50$ MeV) for the $\pi^+\pi^0\nu_\tau$ mode (no $\pi^0$ for $\pi^+\nu_\tau$)
  - Mode-dependent cuts on missing mass, energies of “$\tau$” daughters,
    n-$\pi$ sub-resonance masses ($\rho$, $a_1$)
  - $E_{\text{extra}}$ from remaining neutrals identifies signal
    - Signal: $E_{\text{extra}} < 300$ MeV
    - Background: $350 < E_{\text{extra}} < 1000$ MeV

$D^0\pi^0\nu_\tau$  
$D^0\gamma\nu_\tau$

$\Delta M$ (Gev/c$^2$)  

$E_{\text{extra}}$ validation from double tags

Leptonic B Decays - BaBar preliminary

Gregory Dubois-Felsmann – 5 August 2004
**$B^+ \rightarrow \tau^+ \nu_\tau$ analysis II – event count breakdown**

- Expectations and results for $(124.1\pm1.4) \times 10^6 BB$:

<table>
<thead>
<tr>
<th></th>
<th>$e^+\nu_e\bar{\nu}_\tau$</th>
<th>$\mu^+\nu_\mu\bar{\nu}_\tau$</th>
<th>$\pi^+\bar{\nu}_{\tau}$</th>
<th>$\pi^+\pi^0\bar{\nu}_{\tau}$</th>
<th>$\pi^+\pi^-\bar{\nu}_{\tau}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^+B^-$</td>
<td>8.20 ± 1.60</td>
<td>7.25 ± 1.58</td>
<td>24.18 ± 2.80</td>
<td>14.16 ± 2.21</td>
<td>14.16 ± 2.21</td>
</tr>
<tr>
<td>$B^0\bar{B}^0$</td>
<td>3.36 ± 0.97</td>
<td>1.40 ± 0.63</td>
<td>8.11 ± 1.51</td>
<td>3.64 ± 1.01</td>
<td>7.83 ± 1.48</td>
</tr>
<tr>
<td>Combined</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$B\bar{B}$</td>
<td>11.65 ± 1.95</td>
<td>8.65 ± 1.70</td>
<td>32.29 ± 3.26</td>
<td>17.80 ± 2.43</td>
<td>21.99 ± 2.66</td>
</tr>
<tr>
<td>$\alpha\nu, dd, ss$</td>
<td>0 ( &lt; 2.2 )</td>
<td>0 ( &lt; 2.2 )</td>
<td>9.54 ± 3.02</td>
<td>8.59 ± 2.86</td>
<td>2.86 ± 1.65</td>
</tr>
<tr>
<td>$\tau^+\tau^-$</td>
<td>0.48 ± 0.48</td>
<td>0 ( &lt; 1.1 )</td>
<td>2.87 ± 1.17</td>
<td>0.48 ± 0.48</td>
<td>0 ( &lt; 1.1 )</td>
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<tr>
<td>Combined</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>non $B\bar{B}$</td>
<td>0.48 ± 0.48</td>
<td>0</td>
<td>12.41 ± 3.24</td>
<td>9.07 ± 2.90</td>
<td>3.67 ± 1.84</td>
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<tr>
<td>Total Background</td>
<td>12.12 ± 2.01</td>
<td>8.65 ± 1.70</td>
<td>44.69 ± 4.59</td>
<td>26.86 ± 3.79</td>
<td>25.67 ± 3.24</td>
</tr>
<tr>
<td>Expected signal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>events for $BR(B^+ \rightarrow \tau^+\nu_\tau)$</td>
<td>2.03 ± 0.10</td>
<td>1.16 ± 0.07</td>
<td>5.26 ± 0.16</td>
<td>0.76 ± 0.06</td>
<td>0.50 ± 0.05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>BG incl. systematic unc’y</th>
<th>Observed</th>
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<tbody>
<tr>
<td>Total</td>
<td>15.2±3.1</td>
<td>13</td>
</tr>
<tr>
<td>$e^+\nu_e\bar{\nu}_\tau$</td>
<td>8.1±2.1</td>
<td>10</td>
</tr>
<tr>
<td>$\mu^+\nu_\mu\bar{\nu}_\tau$</td>
<td>55.3±7.4</td>
<td>72</td>
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<tr>
<td>$\pi^+\bar{\nu}_{\tau}$</td>
<td>29.8±5.1</td>
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<tr>
<td>$\pi^+\pi^0\bar{\nu}_{\tau}$</td>
<td>25.1±3.4</td>
<td>26</td>
</tr>
</tbody>
</table>
**$B^+ \rightarrow K^+ \nu \bar{\nu}$ analysis details**

- **Semileptonic tags**
  - $D^0$ mesons are reconstructed in $D^0 \rightarrow K^- \pi^+, K^- \pi^+ \pi^-, K^- \pi^+ \pi^0$
  - Leptons are identified as $e, \mu$
  - Require $-2.5 < \cos \theta_{B,Dl} < 1.1$ (accepts $D^{(*)0}$); reject tags with extra $\pi^\pm$ consistent w/$D^{**}$

- **Hadronic tags**
  - $D$ mesons and $D^0 X^-$ combinations are reconstructed as stated earlier, selecting on $m_{ES}$ and $\Delta E$.

- **Signal determination**
  - Require exactly one additional charged track, a well-identified kaon. Reject $\pi^0$’s, >6 neutrals.
  - Compute $E_{\text{extra}}$ as above
  - Count events:
    - Signal: $E_{\text{extra}} < 250$ MeV, $p_K^* > 1.25$ GeV/c
    - Continuum and combinatoric $B$ background determined from sidebands (of $D^0$ and $B$);
    - “Peaking” $B$ background determined from simulation for hadronic analysis, not subtracted in semileptonic

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Leptonic B Decays - BaBar preliminary 21

Gregory Dubois-Felsmann – 5 August 2004
**B^0 → invisible (ν ¯ν), ν ¯ν γ analysis overview**

- **Semileptonic tags only:** $B^0 \rightarrow D^{(*)+} l \bar{\nu}$ ($D^{*+} \rightarrow D^0 \pi^+$)
  - with $D^+ \rightarrow K^- \pi^+ \pi^+$ and $D^0 \rightarrow K^- \pi^+$, $K^- \pi^+ \pi^+$, $K^- \pi^+ \pi^0$
  - Require $-2.5 < \cos \theta_{B,D^{(*)}l} < 1.1$ (accepts some higher $D^{*(*)}$’s)
  - Result: 126108 tags, purity 66%

- **Reconstruct “nothing”**
  - No additional charged tracks
  - $\nu \bar{\nu}$: $N(\gamma$-like” clusters in EMC) < 3, $N(K^0_L$-like” clusters) < 3
  - $\nu \bar{\nu} \gamma$: Exactly 1 EMC cluster with $E_\gamma^* > 1.2$ GeV
  - Again look at $E_{\text{extra}}$

- **Determine signals:**
  - Construct PDFs in $E_{\text{extra}}$ for signal, background
    - Non-parametric KEYS PDFs used
    - Perform unbinned ML fit to distribution in data

- **Validations:**
  - Efficiency checked against double tags
  - Analyses repeated in “$B^+ \rightarrow$ invisible” control sample